TITLE: Study of a Helium Atmospheric Pressure Dielectric Barrier Discharge at 100 kHz

Study of a helium atmospheric pressure dielectric barrier discharge at 100 kHz

R. Foest[1], V. A. Maiorov[2,3], Yu. B. Golubovskii[2], J. F. Behnke[3], M. Schmidt[1]
[1] Institute of Low-Temperature Plasma Physics, F.-L.-Jahnstrasse 19, 17489 Greifswald, Germany
[2] St. Petersburg State University, Physical Faculty, Ulianovskaja 1, Petrodvorets, 198904 St. Petersburg, Russia
[3] University of Greifswald, Institute of Physics, Domstrasse 10 a, 17489 Greifswald, Germany

A homogeneous atmospheric pressure glow discharge is obtained in helium at 100 kHz. The electrical characteristics of the discharge are measured and compared with the results of the model. The calculations agree well with the experiment when a small admixture of nitrogen is assumed and the destruction of the helium excimers is strong enough. A multi-peak structure of the current is observed at higher amplitudes of the external voltage.

1. Introduction

Non-thermal plasmas are widely used for plasma processing. Atmospheric pressure plasmas require practically no vacuum devices. The atmospheric pressure dielectric barrier discharge (DBD) has been used for a long time, starting with the ozone generation by Siemens 1857. The DBD is mostly a filamentary one, however, a homogeneous DBD was found in He and later in other gases too [1]. Studies of the homogeneous He discharge cover the frequency region of 50 Hz to 50 kHz with two dielectric barriers in the gap. In our work we extend the frequency region to 100 kHz. Moreover, only one electrode is covered by a glass dielectric. The other electrode is plain aluminium.

2. Experimental technique

The experiments were carried out in a cylindrical glass vessel (d=200 mm, l=400 mm, Fig. 1), which is, along with the measuring method of the electrical parameters, described elsewhere [2]. Residual gas pressures are about 20 Pa. The upper electrode (80x15mm, covered with glass) is powered with a sinusoidal voltage while the lower Al electrode is connected to ground by R_m or C_m resp.

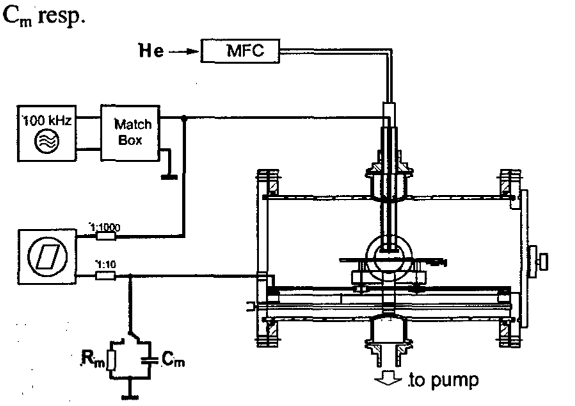

Fig. 1. Experimental set-up

The electrode distance was kept at 1.5 mm for the experiments described here.

3. Model

The simulation of the homogeneous barrier discharge is based on the continuity equations for electrons, ions, and metastable atoms and molecules, and the Poisson equation. The mobility, diffusion, excitation and ionization coefficients are calculated on the basis of the Boltzmann equation. The interaction between plasma and electrodes is described by boundary conditions. We assume the emission coefficients γ to be equal to 0.05 for glass and 0.1 for metal. Electron desorption plays no role in the glow discharge.
In helium, relatively large densities of metastable states can occur due to their ineffective destruction [3]. Hence, different ionization channels must be considered to describe the helium discharge properly (Fig. 2).

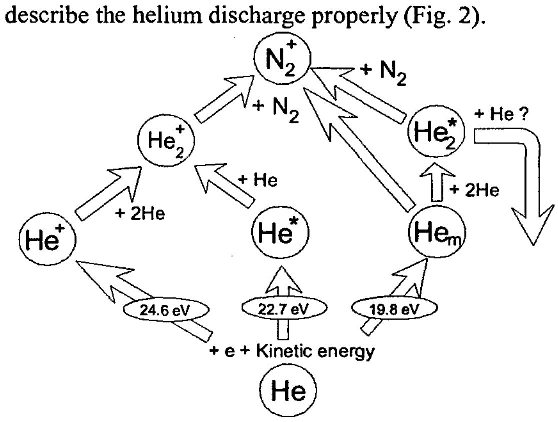

Fig. 2. Channels of ionization in helium

Besides the direct ionization, there is the Hornbeck-Molnar process, i.e., the ionization by collision of highly excited states with helium atoms, and the most effective Penning ionization. At high pressure, the conversion of ions causes the formation of impurity (N_2) ions within the time of 0.1 μs.

4. Results and discussion

We applied amplitudes of the sustaining voltage between 0.66 and 1.63 kV and obtained the homogeneous glow discharge throughout the whole range.

The experimental and calculated electrical characteristics of the discharge at 1.2 kV are shown in Fig. 3. Theory and experiment are in good agreement.

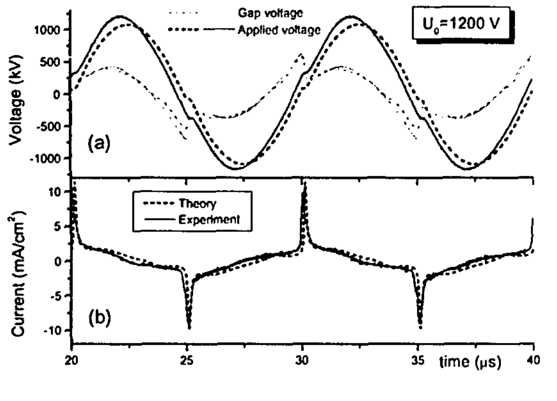

Fig. 3. Comparison of the experimental and theoretical curves of gap and applied voltages (a) and current (b)

The breakdown occurs as the gap voltage attains the value of 0.6 kV. In this phase, the applied voltage is slightly disturbed due to the nonideality of the power supply (in the theory, we use the external resistance R=50 kΩ). Positive and negative current peaks have different amplitudes; the larger peak occurs when the metal electrode serves as cathode.

We should note the following aspect of the ionization kinetics. When the ionization scheme shown in Fig. 2 is used, the excitation of metastable helium is followed by ionization with almost 100% efficiency. The breakdown voltage in this case is about 0.3 kV. Therefore an effective destruction mechanism for metastable states has been assumed to achieve better agreement with the experiment. A possible mechanism is the transition of a vibrationally excited excimer molecule to the radiating state via collision with a helium atom. The destruction frequency in our model is taken to be 10^6 s^{-1}.

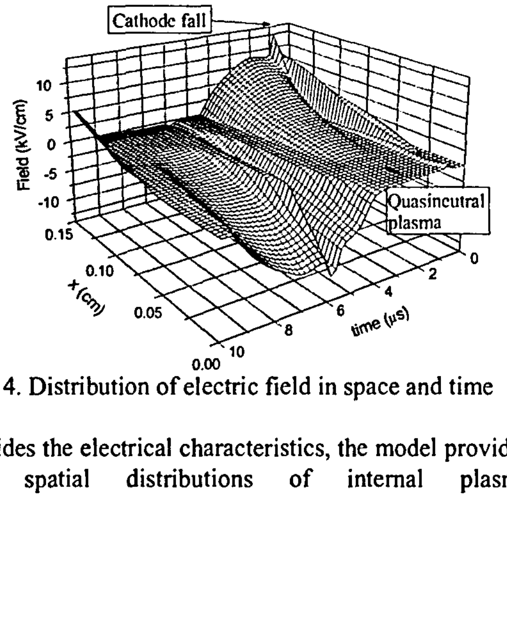

Fig. 4. Distribution of electric field in space and time

Besides the electrical characteristics, the model provides the spatial distributions of internal plasma characteristics. In Fig 4 the distribution of the electric field is shown.

During the breakdown, a cathode fall region with strong electric field is developed. After this phase, a positively charged cathode sheath and quasi neutral plasma region with zero field can be seen. The strong field in the cathode region can accelerate the ions efficiently, which can be useful for surface modification applications.

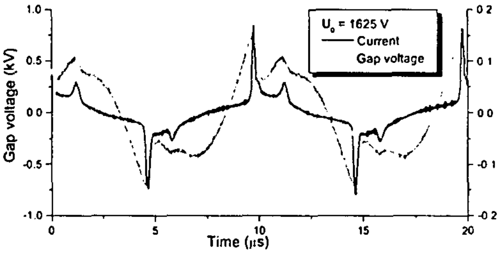

Fig. 5. Current and gap voltage for two-peak mode

At higher amplitudes, a second current peak is observed (Fig. 5). Such a multi-peak structure was observed by other authors too [4], where it was proven that the second peak corresponds to the breakdown at the periphery of the discharge gap.

5. Conclusion

We consider the study of the homogeneous DBD in He as a valuable contribution to the understanding of the discharge mechanism. The promising results of the simulation encourage us to study other gas mixtures too and to apply the model to gases with a technical relevance to surface treatment.

6. Acknowledgements

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